Notes relating to the experiment and observations to measure Hogan's noise
R. Weiss May 15, 2009 (revised May 17, 2009)

1) Upper limits to the Hogan noise

The LIGO 4km (H1) and 2km (H2) interferometric gravitational wave detectors in the same envelope at Hanford offer a technique to measure the Hogan noise. The S5 run provided one year's worth of data that is being crosscorrelated. LIGO measures the longitudinal strain with resonant cavities in the interferometer arms. Hogan's noise is a transverse strain. The resonant cavities are not sensitive to this transverse fluctuation, however, the plane that contains the beam splitter and one of the cavities responds to the transverse fluctuations. The transverse strain sensitivity is poorer by a factor of $\sqrt{2}$ times the finesse of the Fabry-Perot cavity in the arm - a factor of 150 . The spectral response is the same as for the longitudinal strain.

The LIGO Scientific Collaboration Search group for a stochastic gravitational wave background has written a paper (about to be published in *Nature)* describing the results of the crosscorrelation of the L1 (Livingston, Louisiana 4km) with H1 using data from S5. The analysis of the cross correlation of H1 with H2 is still in process. The data from the two colocated interferometers is correlated in various narrow frequency bands below 300 Hz. These correlations are associated with environmental perturbations that are common to the two interferometers. The environmental correlations between H1 and H2 could cause a bias in the integral of the crosscorrelation that can go in either positive or negative directions depending on the phase difference of the perturbing excitation in the H1 and H2 interferometers. The correlations get in the way of a clean sensitive measurement of a stochastic background and this is one of the reasons why the data has not yet been published. Nevertheless, in a test for the Hogan noise, the cross correlation still provides an interesting upper limit. The strain spectral density after integration for 2 months, excluding frequencies below 400 Hz in the crosscorrelation spectrum, gives $h(f) < 8 \times 10^{-25}\ 1/\sqrt{\mathrm{Hz}}$ (Sean Morris, UT Brownsville as relayed by Stefan Ballmer). The transverse strain spectrum associated with this upper limit is $h(f) < 2 \times 10^{-22}\ 1/\sqrt{\mathrm{Hz}}$ comparable (in fact equal) to Hogan's white noise spectrum. The expectation is that when the full year data is used the upper limit will be reduced by a factor of 1.5, and could be reduced further if the full bandwidth down to 50Hz is used with corrections for the correlated noise. To get a robust upper limit on the Hogan noise will require doing stability tests on the data such as leaving out different frequency bands and partitioning the data in time. *I have been urged to say that the H1 H2 correlation data is preliminary and has not been vetted by the LIGO collaboration. It should not be put into publications.*

Another, less sensitive measurement has also been done during S5 using the cross correlation of H1 and H2 at 37.5 kHz, the resonance frequency of the optical cavities in the arms one free spectral range above the main longitudinal resonance. The noise in a 400 Hz wide band embracing the 37.5kHz, was crosscorrelated yielding an upper limit of $h(f) < 2 \times 10^{-23}\ 1/\sqrt{\mathrm{Hz}}$. The upper limit for the transverse strain spectrum is $h(f) < 3 \times 10^{-21}\ 1/\sqrt{\mathrm{Hz}}$. (S. Giampanis, A. Melissinos, N. Christsensen)

The H2 interferometer will be shut down for the Enhanced LIGO run, S6, beginning in July 2009. No new data will come from LIGO relevant to improving the limits on the Hogan noise. I also do not anticipate that an idea to run H1 and H2 as long baseline power recycled Michelson interferometers, by removing the cavity input mirrors, will be carried out given the press of other projects leading to Advanced LIGO.

2) Additional thoughts on dedicated experiments to measure the Hogan noise

To give the Hogan hypothesis a fair test requires more than the upper limit from H1 and H2 and the results of the dual recycling experiment being performed on GEO 600, which could approach the predicted value, if all the other contributing noise is understood. It is clear that if Hogan's daring idea remains viable, it deserves a real test. A test with sufficient sensitivity to allow for the factors of 2 and π or even 4π that have been inadvertantly neglected in Hogan's initial estimates. The remarkable thing is the relatively hugh size of the Hogan noise compared to the limits in the technology that have been found in the interferometric detectors. It is not hard to get the sensitivity required to test the hypothesis, especially if one exploits the idea of the correlations between interferometers and the prediction that the noise has a flat spectrum upto the frequency c/2L. Additional phase sensitivity over the concept design can come from several directions if needed. The power estimates and the mirror quality used in the concept study are modest. More power and better mirrors could well be used. One could imagine another factor of between 10 to 30 reduction in the observing time by placing more aggressive demands on the mirror loss and laser power. A dual recycled Michelson would provide improved phase noise but with reduced bandwidth, even so,one could imagine reducing another factor of between 10 to 30 in observing time with such an interferometer configuration but at the cost of greater complexity. I expect the real problems in a test of the Hogan idea will come from unanticipated correlations between the interferometers.

With this in mind, I strongly encourage people at the meeting to think about systematic problems that could arise in the proposed experiment and to look into techniques that simplify the diagnostics. Several additional ideas have been discussed which have merit.

1) Maintain the ability to measure the cross correlation spectrum. This has proved critical in the LIGO analysis for a stochastic background to search for spurious correlations. Doing this easily argues for a completely digital data analysis system with fast A/D converters and sufficient storage space to hold hours of full bandwidth data. Think carefully about what may get lost by heterodyning .

2) Extend the signal frequency range past c/2L to investigate how the correlations between the interferometers change above the Hogan band.

3) Make every effort to keep the sources of fast fluctuations in the two interferometers independent. It is worth using two separate vacuum systems, two different lasers, two independent detection systems. Clearly, excellent electromagnetic shielding to avoid RF pickup is central to the design.

4) Provide a means for changing the Hogan correlation. One idea is to have enough room to slide one interferometer past the other and meaure the change in the correlation for a set of separations.The technique that has been discussed is a translation along one of the arms. It might be useful to think of relative rotations.

Design choices in the concept study

In the concept design I chose fixed PZT actuated mirror mounts as the baseline to avoid the complexity of suspended masses in a regime where the signals would be significantly above the noise from stochastic forces. The PZT system need to have the dynamic range to remove the low frequency seismic noise. With a reasonably quiet location, it does not seem difficult to hold the fringe well enough against the few micron seismic motion. It is also assumed that the angular noise is small enough to be either neglected or to be removable by a low bandwidth system using dithering. I have encouraged the vacuum system designers to make enough room in the small chambers to allow suspended masses if the baseline design is inadequate. One of the possible fears is up-conversion from large seismic excitations which could be better controlled with suspended masses.

Another design variable is whether it is necessary to place the photodetectors in the vacuum. The assumption made is that will be necessary but that one starts with the detectors outside in air.

An interferometer arm length of 40 meters was chosen for the baseline. It seemed a good choice given a set of factors. First, the 40 meter system at Caltech is being rebuilt by Rana Adhikari and there may well be optical components that could be borrowed. The cube dependence of the integration time with length gave easy factors in the sensitivity. At Fermi lab there were locations that could handle 40 meters and it seemed appropriate to favor longer baselines to give practice for the follow on Axion generation experiment.

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